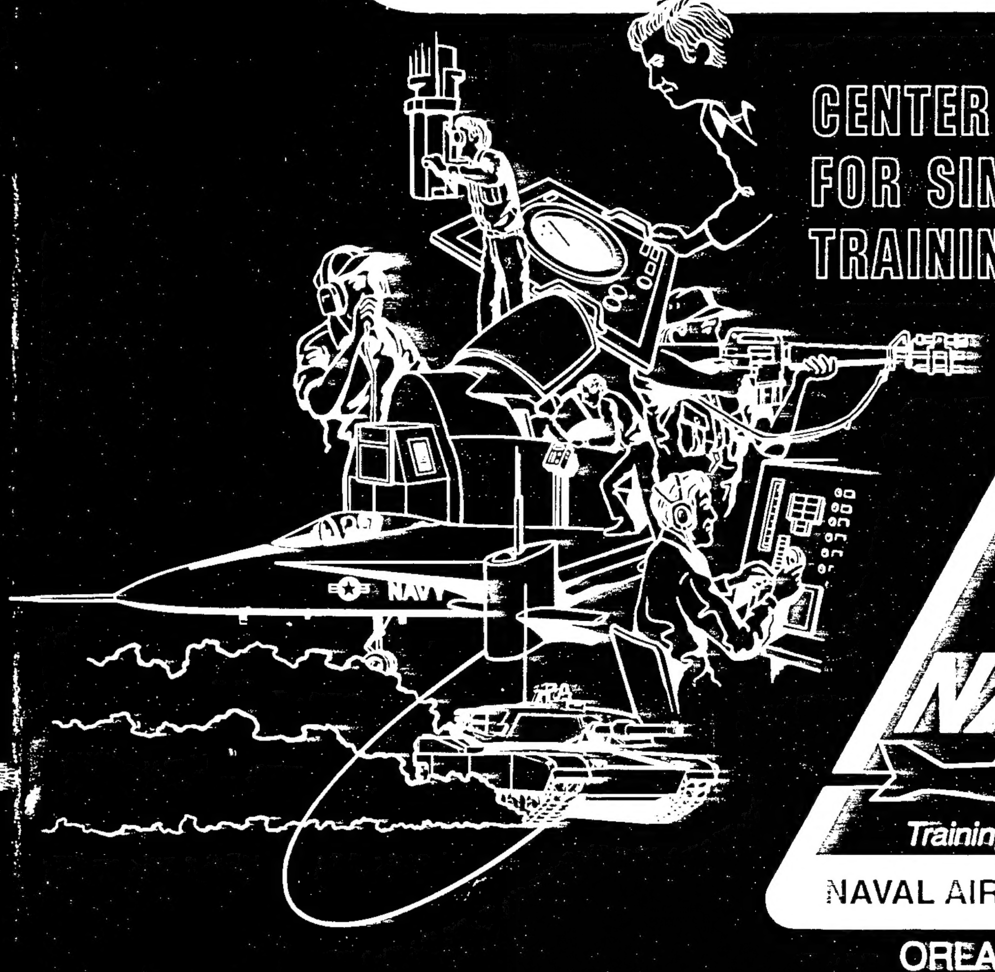
NAVAL AIR WARFARE CENTER
TRAINING SYSTEMS DIVISION
ORLANDO, FLORIDA

TECHNICAL REPORT 97-013

USER-ORIENTED DESIGN ANALYSIS OF THE VESUB TECHNOLOGY DEMONSTRATION SYSTEM

NOVEMBER 1997



CENTER OF EXCELLENCE FOR SIMULATION AND TRAINING TECHNOLOGY

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13. ABSTRACT (*Maximum 200 words*)

This report documents the Instructor Station usability analyses conducted during the formative evaluations of the Virtual Environment for Submarine OOD Ship Handling (VESUB) technology demonstration system. Students from a graduate level “Human-Computer Interaction Usability Evaluation and Design” class at the University of Central Florida conducted user-oriented design analyses of the VESUB Instructor/Operator Station (IOS) using standard usability heuristics. The analyses revealed numerous design violations which could reduce the effectiveness of operational versions of VESUB. The VESUB research team conducted a post-hoc analysis of their results, focusing on the most critical design violations which must be corrected to improve the usability of the operational VESUB IOS. A discussion of these design violations and recommendations for improved VESUB IOS design are provided. Finally, five general areas for future research to improve IOS designs are discussed: 1) standardization of graphical user interfaces; 2) development of on-line help for the instructor; 3) development of embedded instructor training; 4) application of task analysis methods to instructor tasks; and 5) use of voice recognition at the instructor station.

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The authors would also like to thank the Navy instructors and fleet subject matter experts who provided valuable information on the design and usability of the VESUB system.

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EXECUTIVE SUMMARY

PROBLEM

In recent years, virtual reality (VR), often called virtual environments (VE), has received an enormous amount of attention among training developers. This is due in part to media hype over applications of VR in the entertainment industry, but even more so because training developers recognize the potential of VR as a flexible and effective training medium. Training effectiveness evaluations of VR training systems can help define the appropriate use of VR technologies to achieve this potential. Moreover, as with all training media, the potential of VR can not be achieved unless VR training systems are usable by the instructors and trainees for whom they are developed.

A prime candidate task area for examining the effectivness and usability of VR systems is the training of submarine surfaced ship handling. Although land-based simulator facilities currently exist for training Submarine Piloting and Navigation teams, these systems do not provide detailed harbor and channel ship handling training for the Officer of the Deck (OOD). OOD training is primarily obtained from on-the-job experience, which is adversely impacted by the operational constraints of the Submarine Force, and the limited surfaced steaming time of submarines. Training that will expose junior officers to a variety of geographical and environmental conditions is very limited since most Commanding Officers place their most experienced OODs on watch during these challenging evolutions. Therefore, an alternative, simulation-based training capability is needed. A VR-based simulation may provide this necessary capability if it is both effective and user-friendly.

OBJECTIVE

The objective of the Virtual Environment for Submarine Ship Handling and Piloting Training (VESUB) project is threefold: (1) to develop, demonstrate, and evaluate the training potential of a stand-alone virtual reality-based system for OOD training; (2) to determine if this system can be integrated with existing Submarine Piloting and Navigation (SPAN) training simulators, and (3) to determine the viability of virtual reality technology as a training tool. This report looks at the user-oriented design issues for the VESUB Instructor/Operator Station (IOS). The ability of Navy instructors to use the VESUB system will be critical to the effectiveness of the training system. The results of the user-oriented design analysis, as documented in this report, will be used in conjunction with the results of training effectiveness evaluations (to be documented in a separate publication) so the design of the follow-on operational VESUB system can incorporate the latest technologies and also to be as user-friendly as possible.

APPROACH

The students from a graduate level "Human-Computer Interaction Design and Evaluation" class at the University of Central Florida conducted usability analyses of the VESUB Instructor/Operator Station (IOS) during the formative evaluation phase of system development.

These analysts applied Nielsen's (1993) design criteria to identify numerous IOS usability violations. The results of these analyses were further analyzed by the VESUB research team to determine the most critical usability design violations that require correction in the operational VESUB system.

RESULTS

Four separate analysis reports were produced for class credit and provided to the VESUB research team. The reports documented both major and minor usability design violations. Some of these violations were corrected in later software iterations. A post-hoc analysis of the high priority design violations that could not be corrected in the demonstration system identified twenty-two areas where the design of the operational VESUB system IOS could be improved.

RECOMMENDATIONS

Of the twenty-two IOS design violations that are discussed, one has been corrected in the demonstration system, five have been partially corrected, and sixteen require correction in the operational VESUB system. The training implications of these design violations are discussed.

In addition to the recommended improvements to the design of the operational VESUB systems, five general areas for research are recommended to improve the usability of any future instructor station. These areas were chosen on the basis of the lessons learned during VESUB development and their potential to improve the performance of the instructor at the IOS. They are: 1) standardization of graphical user interfaces; 2) development of on-line help for the instructor; 3) development of embedded instructor training; 4) application of task analysis methods to instructor tasks; and 5) research on the use of voice recognition at the IOS.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

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INTRODUCTION

PROBLEM

In recent years, virtual reality (VR), sometimes called virtual environments (VE), has received an enormous amount of attention among training developers. This is due in part to media hype over applications of VR in the entertainment industry, but even more so because training developers recognize the potential of VR as a flexible and effective training medium. Training effectiveness evaluations of VR training systems can help define the appropriate use of VR technologies to achieve this potential. Moreover, as with all training media, the potential of VR can not be achieved unless VR training systems are usable by the instructors and trainees for whom they are developed. The Virtual Environment for Submarine OOD Ship Handling Training (VESUB) technology demonstration system provides an opportunity to evaluate Instructor/Operator Station (IOS) design alternatives for both the operational (follow-on) VESUB system and other future VR-based training systems.

OBJECTIVE

This is the first in a series of reports to document the results of the VESUB project. It discusses the user-oriented design issues in the development of the instructor station for a VR training system technology demonstration for submarine ship handling, called VESUB . Although the design issues are discussed in the context of the VESUB technology demonstration system, they are applicable to any computer-based training system that includes an instructor station. The results of this usability analysis will be used in the development of the specifications for the operational VESUB system. This analysis should also serve to help the design of the instructor stations for other future training systems. Other reports will document the results of the VESUB training effectiveness evaluations and lessons learned from the project. It is hoped that these reports will provide guidance to increase the training effectiveness of future VR training systems.

ORGANIZATION OF THE REPORT

The first sections provide a brief overview of the submarine ship handling task and the need for the VESUB training system. A brief overview of VR training research explains why submarine ship handling was chosen as the technology demonstration task. A description of the developmental phases and formative evaluations of the VESUB technology demonstration system and the need for usability analyses are also provided. The next section is a discussion of user-oriented design approaches and the design heuristics that were applied to the VESUB Instructor Station. The usability analysis method, results, and discussion are presented in the subsequent sections. Finally, recommendations for corrections of VESUB design violations and areas for future research to improve the user-oriented design of instructor stations are provided.

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THE VIRTUAL ENVIRONMENT FOR SUBMARINE SHIP HANDLING AND PILOTING TRAINING TECHNOLOGY DEMONSTRATION SYSTEM (VESUB)

BACKGROUND

Land-based simulator facilities currently exist for training Submarine Piloting and Navigation teams. These systems do not, however, provide detailed harbor and channel ship handling training for the Officer of the Deck (OOD). OOD training is primarily obtained from on-the-job experience, which is adversely impacted by the operational constraints of the Submarine Force, and the limited surfaced steaming time of submarines. Training of junior officers under a variety of geographical and environmental conditions is very limited since most Commanding Officers place their most experienced OOD on watch during these challenging evolutions. Therefore, an alternative, simulation-based training capability is needed and may be met effectively and economically using virtual reality (VR).

Research in Virtual Reality

VR has received considerable publicity in recent years from the entertainment industry (e.g., Brill, 1994; Gradecki, 1994) and the popular press (e.g., Rinegold, 1992; Kalansky, 1993; Burdea & Coiffet, 1994). VR has also generated considerable interest in the military (e.g., McVey, 1993; Cook, 1994; Lampton, Knerr, Goldberg, Bliss, Moshell, & Blau, 1994; Knerr, Goldberg, Lampton, Witmer, Bliss, Moshell, & Blau, 1994) and NASA (e.g., Null & Jenkins, 1993).

Traditional military training systems have used operational equipment, large training ranges, or expensive simulation equipment. VR affords the potential to greatly reduce the cost of training systems because it can provide a trainee with an interface to training equipment without the necessity of replicating expensive hardware. Furthermore, VR training can be provided on a range of tasks using the same basic trainee interface by changing the VR software. This can potentially save huge amounts of resources which would otherwise be required to build a complete new physically different trainee interface. VR also offers the potential to provide new and innovative training strategies that can only be applied in a virtual world. For example, a trainee could view the inside of a fuel system from the perspective of a molecule of gasoline; he or she could grow to the size of a giant to view a tactical engagement from above, then jump from one ship to another for various points of view; or a trainee could engage in team training with virtual team members. However, the potential of VR training can not be achieved unless researchers demonstrate the effectiveness of VR training systems.

Research in VR is being conducted at various laboratories (e.g., the Army Research Institute, and the Navy Post Graduate School) in three modality areas: visual, auditory, and haptic. Visual research includes efforts to improve display devices (e.g., head-mounted displays [HMDs] and "cave" projection screens) and head tracking systems. The visual modality is the most highly advanced area of VR research. Among other questions, auditory research is examining the effectiveness of the use of highly realistic and 3-D localized sounds in virtual worlds. Research on haptic displays seeks to improve the simulation of both the tactile (cutaneous) and kinesthetic (muscle and joint) aspects of virtual touch. It is the least mature of the three VR modalities.

The VESUB Project

The Virtual Environment for Submarine Ship Handling and Piloting Training (VESUB) is a Navy Manpower, Personnel, and Training R&D project with the goal to develop, demonstrate, and evaluate the training effectiveness of a VR-based system for surfaced submarine OOD training. The submarine ship handling task was chosen as the task area for the technology demonstration for three reasons: 1) there is a clear Navy need for this training; 2) submarine ship handling is a visually dependent task; and 3) the visual modality is the most mature of the three areas of VR development. If effective, VESUB has the potential to reduce the number of ship handing mishaps, save lives, and reduce property loss. Based on the results of the VESUB R&D effort, the Navy will procure five operational VESUB systems to be installed at the main submarine training facilities throughout the United States.

The VESUB system was developed by Nichols Advanced Marine (formerly Advanced Marine Enterprises, [AME]) under contract and direction of a research team at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, FL. The research team includes: research psychologists, visual engineers, computer engineers, and submarine subject matter experts. To save time and money, VESUB was developed by leveraging AME's Virtual Ship, a commercial product that has been used for several years to train surface ship handling tasks. Installations of Virtual Ship use large projection screens to display the visual scene and full bridge mock-ups for the trainee interface. These systems also require several full-time instructors to operate their very complex instructor stations.

Under the VESUB project, AME has modified Virtual Ship by using head-mounted display (HMD) and magnetic head tracking technologies to present the visual scene to trainees (see system description below). The VESUB project has also required AME to enhance the level of detail and fidelity in the visual databases far beyond previous systems. Furthermore, in addition to advancements in the hardware and software technologies used in Virtual Ship, VESUB has introduced numerous improvements in the design of the instructor interface so it can be easily used by Navy instructors. However, schedule and budget constraints have limited the scope of these improvements in the technology demonstration VESUB system, but the results of this analysis can be used to ensure that the operational VESUB system is designed to be as user-friendly as possible.

VESUB SYSTEM OVERVIEW

The VESUB technology demonstration system uses a high-resolution head mounted display (HMD) to provide the trainee with a simulated 360 degree visual environment containing all of the required cues associated with harbor and channel navigation as well as accurate cultural features and varying environmental conditions. Voice recognition and synthesis are used to provide communications training. Visual scene rendering, computation of harbor currents and wind effects, and operation of own ship and other traffic ships require state-of-the-art computer systems and software packages. Appendix A lists and describes the hardware and software used in VESUB.

Figure 1 shows an artist's depiction of the VESUB system. On the right side of the figure, an instructor is shown seated in front of the three monitors at the Instructor/Operator Station (IOS). Screens on two of the IOS monitors are used to modify and control training scenarios. The third monitor is used to observe the virtual world that the trainee sees through the HMD during a training exercise. This view allows the instructor to evaluate the trainee's performance in real-time and provide

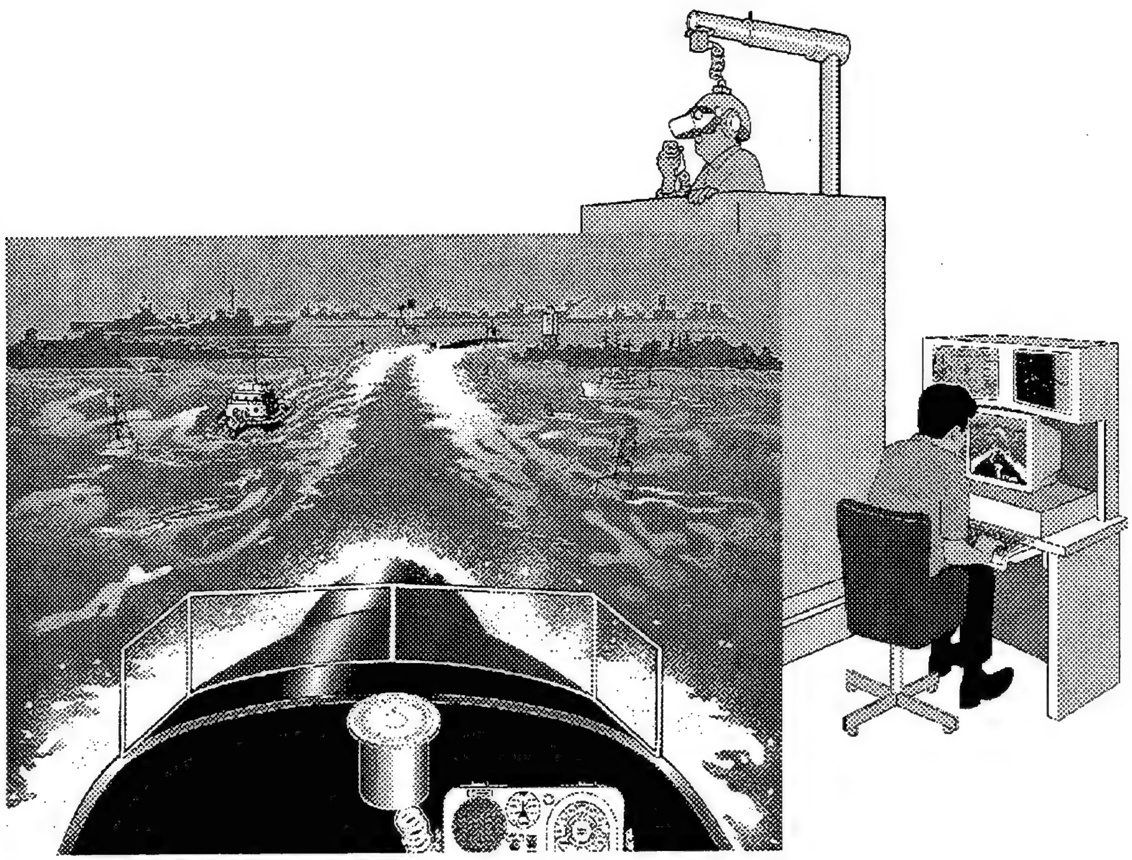

Figure 1: Artist's Representation of VESUB

guidance to direct the trainee to look for the correct objects to support the task. This same monitor is used before an exercise to create the training scenarios. In Figure 1, the trainee is shown standing in the bridge mock-up, wearing the HMD and communicating with a simulated navigation team via a hand-held microphone. The inset depicts a typical harbor scene as the trainee views it through the HMD. The visual scene displays distant objects, including: harbor geographic features, navigation aids, landmarks, and traffic ships. It also displays objects near the trainee, including: a representation of the bridge area (for either the 688I or the 726 classes of submarines), and much of the equipment needed to help the OOD perform the ship handling task. The requirement to display near and distant objects

necessitated the use of new visual scene management processes (e.g., large area database management system) that were not needed in previous ship handling training systems. The trainee is also able to see simplified charts and other piloting information on request via the voice interface. When the trainee turns his head, a magnetic head tracker, mounted above the mock-up, senses the movement and the computer changes the visual scene appropriately. Thus, for example, the trainee is able to turn to the stern and observe the rudder move in response to an issued helm order. Visual obstacles, such as lookouts, periscopes, and radar masts can be displayed at the discretion of the instructor to make the training task more realistic by forcing the trainee to look around them to see critical visual cues.

The Submarine Ship Handling Task

A submarine, when surfaced, must perform according to the ship handling procedures followed by surface ships. Current submarine OOD ship handling training, since it is primarily conducted on-the-job, requires each ship's Commanding Officer (CO) to evaluate the performance of junior officers (JOs) prior to certifying them as qualified OODs. In the early phases of the VESUB project, submarine COs were interviewed to determine how they accomplished this task. In almost every case, the COs responded that their personnel were qualified when they had developed the "Seaman's Eye." This concept was, therefore, used as the keystone for the development of VESUB training objectives. For the purposes of the VESUB effort, the following definition of "Seaman's Eye" was developed to guide the research.

> *Seaman's Eye: The total situation awareness of the ship handling environment and the ability to safely maneuver the vessel in all conditions.*

This definition was still too general to serve as a guide for the development of VESUB hardware and software requirements and training objectives. Therefore, iterative probing of subject matter experts (SMEs), using focused group discussions at Navy training facilities and the NAWCTSD laboratory, helped reveal a variety of perceptual and cognitive components that make up this complex concept. Additional group discussions with the SMEs helped the VESUB research team to organize the components as shown in Table 1.

The perceptual components of "Seaman's Eye" were initially used to determine the hardware requirements for the system. For example, the requirement to locate and identify navigation aids (P1) and to judge distance (P2) required that the trainee be able to see the objects at large distances and necessitated the use of a high resolution HMD. The requirement to visually inspect the rudder necessitated the use of head tracking and rapid refresh rate of the visual scene. Details on the hardware determination for VESUB can be found in Hays, Castillo, Bradley, and Seamon (1997). Both the perceptual and the cognitive components were used to develop and organize the training objectives for the VESUB system. The training objectives, shown in Appendix A, were used to develop the training and evaluation criteria for the VESUB Training Effectiveness Evaluations (TEEs). The results of the TEEs will be documented in a separate report.

Table 1

Components of "Seaman's Eye"

PERCEPTUAL COMPONENTS
1P. Locating and Identifying Navigation Aids
2P. Judging Distance
3P. Identifying the Start and Completion of Turns
4P. Locating, Identifying, and Avoiding Obstacles
5P. Sense of Ship's Responsiveness
6P. Recognizing Environmental Conditions
7P. Recognizing Equipment Failures
8P. Detecting and Filtering Communications
COGNITIVE COMPONENTS
1C. Understanding the Relationship of Visual Cues to their Representations on Charts
2C. Understanding Relative Size and Height/Range Relationships, and Angle on the Bow (AOB)
3C. Understanding Advance and Transfer
4C. Understanding the Effects of Tides, Currents, Wind, and Seas
5C. Understanding Rules of the Road
6C. Understanding Relative Motion (Direction and Speed)
7C. Understanding Methods to Differentiate and Prioritize Traffic Contacts
8C. Understanding Ship's Operation Under Harbor Directives
9C. Understanding Methods to Deal with Uncooperative Traffic
10C. Understanding Correct Operation of Ship's Systems
11C. Understanding When and How to Take Corrective Actions
12C. Understanding Effective Communication Procedures

VESUB DEVELOPMENT PHASES

The VESUB project proceeded in three phases: requirements determination, formative evaluations, and training effectiveness evaluations. A major tool used during the requirements determination phase was a feasibility demonstration system developed under the NAWCTSD exploratory research Virtual Environment Training Technology project. The feasibility demonstration system included a simplified harbor scene and submarine model, which was viewed through a low resolution HMD. This system afforded Navy subject matter experts (SMEs) a chance to experience a virtual world. After the SMEs tried the feasibility demonstration system,

questionnaires and interviews were used to solicit detailed functional requirements for the VESUB technology demonstration system from the SMEs. These requirements were documented in a NAWCTSD special report (Tenney, Briscoe, Pew, Bradley, Seamon, & Hays, 1996) and used in conjunction with the work statement to direct the contractor during the development of the VESUB technology demonstration system.

The formative evaluation phase was conducted in the laboratory at NAWCTSD. Whenever AME produced an improved iteration of the VESUB software on their development system, it was installed on the duplicate system in the VESUB laboratory and evaluated against the functional requirements. The VESUB research team included retired Navy submarine SMEs who assisted with the formative evaluations on a daily basis. Data for these formative evaluations were supplemented by inputs from fleet and school SMEs who were brought into the laboratory when their operational schedules permitted. The results of the formative evaluations were provided to the software developers for the next system iteration. The formative evaluations focused on both the functionality of the trainee interface (e.g., the fidelity of objects in the visual scene or the functionality of the voice recognition system), and the usability of the IOS. The results of the usability analyses are presented in later sections.

The training effectiveness evaluations (TEEs) of the VESUB technology demonstration system will be conducted at the Submarine Training Facility in Norfolk, Virginia and the Navy Submarine School in Groton, Connecticut during the Winter and Spring of 1998. The TEEs will use actual Navy trainees with various levels of experience (novice to expert) to determine the effectiveness of the VESUB system and also to help determine how the technology can be integrated into Navy training. The results of the TEEs and other lessons learned during the VESUB project will be documented in separate publications.

VESUB AS A TRAINING SYSTEM

A training system consists of the planned interaction of people, materials, and techniques, with the goal of improved human performance as measured by established criteria on the job (Hays, 1992). It has been demonstrated that training simulators and devices are more effective if they are integrated into a program of instruction that takes advantages of their capabilities (Caro, 1972; Caro, Isley, & Jolley, 1973). It has also been demonstrated that the effectiveness of simulators is hampered by the lack of instructor training on the use of the simulator's training features (Biersner, 1976). An effective training system must integrate numerous subsystems, including: training equipment, school facilities, administration, and instructors (see Hays, 1992 for a discussion of training systems concepts). A lack of training system integration has been shown to compromise the potential of training devices (Caro, 1977; Hritz & Purifoy, 1980; Iffland & Whiteside, 1977).

Although VESUB is a complex configuration of hardware, software, and courseware, these constituents, no matter how well designed, are not sufficient to ensure that it will be an effective training system. For optimum effectiveness, VESUB, or any other training system, must be

usable by the instructors who will operate it. Therefore, the IOS design must be determined by the needs of the instructor, as a critical component of the training effectiveness of the system. The following sections discuss methods of usability analysis, and describe the development and formative evaluation of the VESUB IOS.

TRAINING SYSTEM USABILITY

The effectiveness of any training system can be compromised by the lack of user acceptance. Nielsen (1993) discusses the attributes of any computer system that contribute to its acceptability. Figure 2 (adapted from Nielsen, 1993, p. 25) shows one model of these attributes. System acceptability, shown on the left side of the figure is first broken down into two constituents: social and practical acceptability. *Social acceptability* involves the purpose of a system and the context in which it is used. For example, a training system could be designed to improve a criminal's shoplifting performance. However, such a system would not be socially acceptable in conventional social settings.

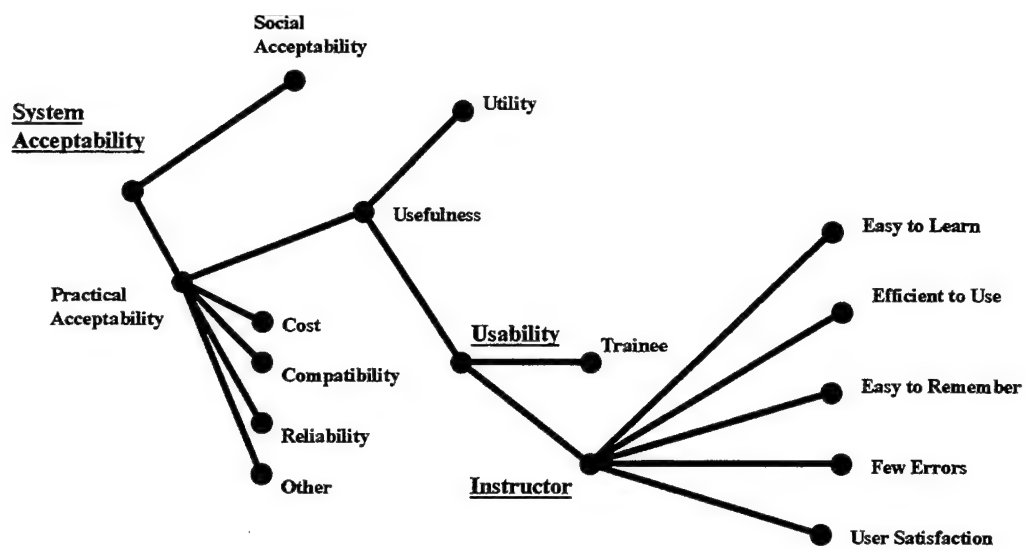

Figure 2: Attributes of System Acceptability (modified from Nielsen, 1993, p. 25)

The other attribute of acceptability is whether the system is *practical*. This involves questions of system cost and system reliability. The hardware of current VR systems, including VESUB, is very costly and somewhat unreliable. Among the goals of VESUB and other VR research programs is to improve system reliability and reduce costs. Demonstrations of the training

effectiveness of systems like VESUB will be a strong stimulus for the user community to push the computer industry toward improvements in these areas.

Another attribute of system practicality is its *compatibility* with other existing systems. One of the goals of the VESUB project is to attempt to interface its modern hardware and software with the older hardware and software of the Submarine Piloting and Navigation (SPAN) trainer. This is a major challenge because each system is based on unique hardware and software configurations. Although not the focus of this paper, hardware interfaces and data compatibility are areas that will require considerable research if VR systems are to reach their potential and be integrated into future training systems and the training community.

The component of practical acceptability that is the focus of this paper is the usefulness of the system. *Usefulness* addresses "the issue of whether the system can be used to achieve some desired goal" (Nielsen, 1993, p. 24). Usefulness questions may address system utility or system usability (Grudin, 1992). *Utility* questions ask whether the system functions as it needs to function. For example, does a training system provide the necessary functionality to meet all major training objectives. This is a major issue with complex computer-based training systems. Often resources are spent on areas of system functionality that make the system perform well at trade shows or other demonstrations, but resources run out before the instructional functionality is included in the system to ensure effective training. Even if instructional features are included in the system, it still may not be useful unless the user is able to efficiently operate it. This is the usability component of usefulness.

Usability questions address how well system users can employ its functionality. For training systems, the two major classes of users are the trainees and the instructors. This report focuses on the usability issues confronted by the instructor. These issues are especially critical for Navy instructors, who do not receive extensive training in instructional techniques. If a training system is not designed to be easy for Navy instructors to use, it is likely to be incorrectly utilized, under utilized, or perhaps not used at all.

The components of system usability are shown in the lower right section of Figure 2. A usable training system should be *easy to learn*. The instructor should not have to spend an inordinate amount of time learning special, system-unique languages or procedures. The faster instructors can learn to use a training system, the more rapidly they can get on with their real work, conducting training. Once the instructor has learned to use the system, it should be *efficient to use*. If the training system is cumbersome, the instructor will spend inordinate amounts of time and energy "driving" the system and not be able to concentrate on monitoring the trainee. The operation of the training system should also be *easy to remember*. The instructor should not have to relearn the system each time he or she accesses a system function after some period of time. The training system should also be designed to *minimize the instructors' errors* during system use. If errors do occur, it should be easy to recover from them. Finally, the instructor should find the training system *pleasant to use*. No instructor will continue to use a training system that he or she finds subjectively unpleasant.

No training system is automatically usable. This is especially true of complex computer-based systems like virtual environments. The goals of the VESUB project included demonstrations of hardware and software. However, the usability of the VESUB technology demonstration was paramount from the beginning of the project. Therefore, the formative evaluations of the VESUB system included Human Computer Interface (HCI) usability analyses of the IOS.

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USABILITY OF THE VESUB INSTRUCTOR/OPERATOR STATION (IOS)

As new technology, VESUB is pushing the state-of-the-art on several fronts. The level of graphics detail and need for rapid screen refresh rate as the trainee moves through the 360 degree environment places heavy computational demands on the system. These computational demands are exacerbated when the submarine hydrodynamic models are modified by the real-time effects of currents, wind, sea states, and other factors. Still additional computational demands are placed on the system when the hydrological properties of the visual scene are changed (e.g., the presence of white caps with increasing wind). The efforts of talented computer programmers have been directed towards optimizing VESUB's hardware resources with the latest programming techniques. However, it is not computer programmers who must be able to use VESUB. The VESUB system will be used by Navy instructors who, like most computer users, possess a basic understanding of computers, but are not computer experts. It has been a major goal during VESUB development and formative evaluations to design the most usable Instructor/Operator Station (IOS) possible. The next sections describe the results of formative design reviews of the VESUB IOS.

VESUB IOS DESIGN REVIEWS

The VESUB instructor has three major responsibilities: 1) operating the system, 2) monitoring the trainee during training exercises, and 3) creating the scenarios to be used in training exercises. The first two responsibilities must be accomplished in real time, while the trainee is interacting with the system. This requires the instructor to watch both the Instructor Station screens and the trainee. If the instructor's attention is too focused on operation of the system, rather than monitoring and coaching the trainee, it is likely that mistakes will be made to the detriment of effective training. The instructor's third responsibility, creation of scenarios, is accomplished off-line with the system's Simulator Generation (SIMGEN) software.

Students from a graduate "Human-Computer Interface Usability Evaluation and Design" class at the University of Central Florida conducted usability analyses of the VESUB Instructor Station during its formative evaluation phase. The analyses applied heuristic usability rules-of-thumb (Nielsen, 1993) to identify usability design violations in the Instructor Station. Before discussing these results, the next section provides a brief description of the VESUB Instructor Station.

Description of the VESUB IOS

The VESUB IOS consists of three computer monitors, each with their own keyboard and mouse. The first screen, called the Simulation Control Display (SCD) is shown in Figure 3 as it appeared at the time of the usability analyses. From the SCD screen, the instructor controls the environmental configuration and other features of the simulation. The SCD screen also provides the capability for the instructor to take manual control of the trainee's submarine or to allow the trainee to control the submarine via the voice recognition system accessed through a microphone located on the bridge mock-up. Using the SCD screen, the instructor has complete control of the

time of day, visibility conditions, sea states, wind, currents, and other visual features of the simulation. In order to access the environmental controls, the instructor must select the

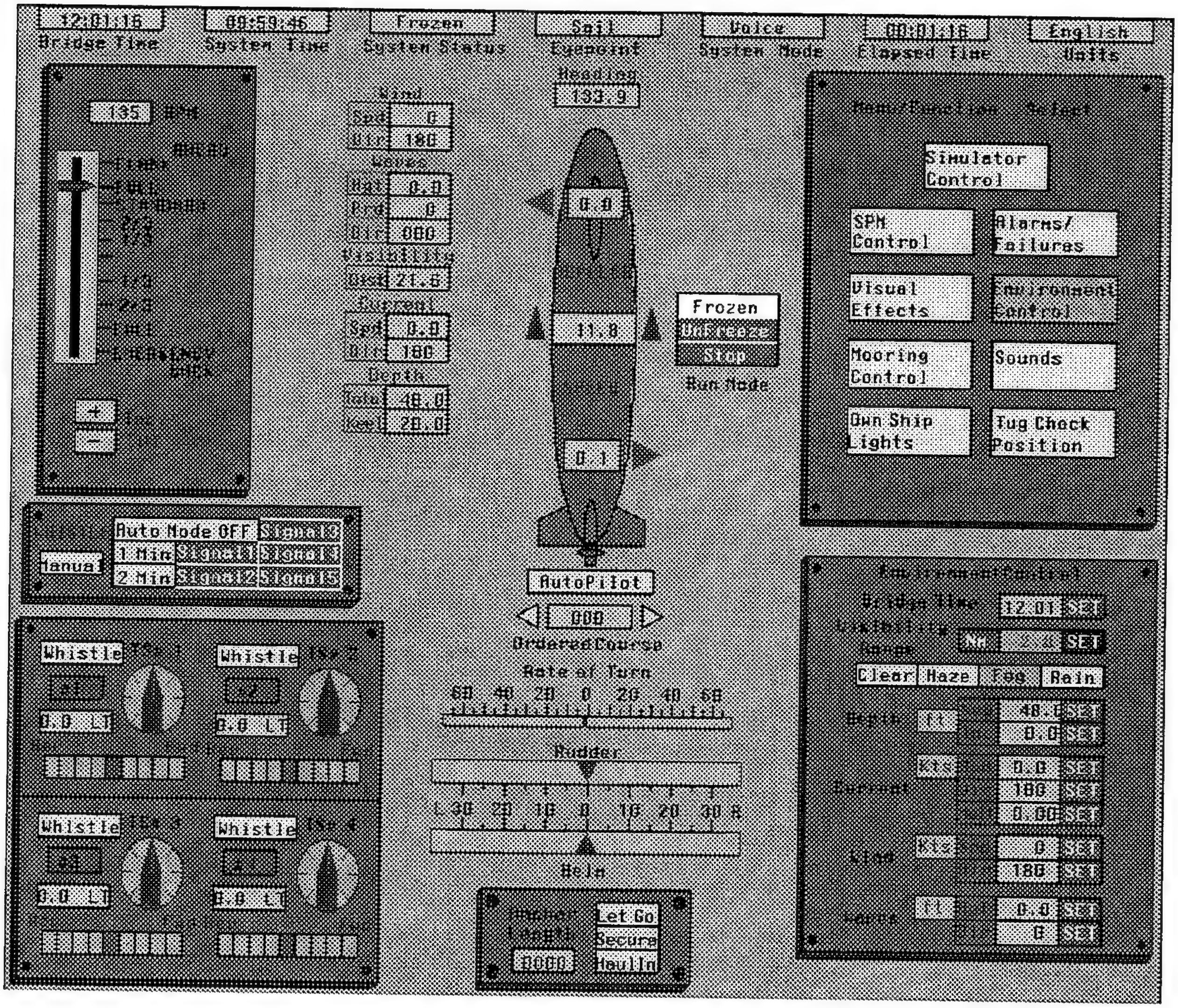

Figure 3:
VESUB Simulation Control Display (SCD) Screen

"Environment Control" button from the main menu in the upper right quadrant of the screen. This selection brings up the "Environment Control" window in the lower right quadrant. Figure 3 shows the SCD with "Environment Control" selected. Other features are accessed in a similar manner when they are selected from the main menu.

The second IOS screen, called the Visual Simulation Display (VSD), is shown in Figure 4. Using the VSD screen, the instructor controls the placement of the ownship (the trainee's submarine) and all the traffic ships used in a training exercise. From the VSD screen, the

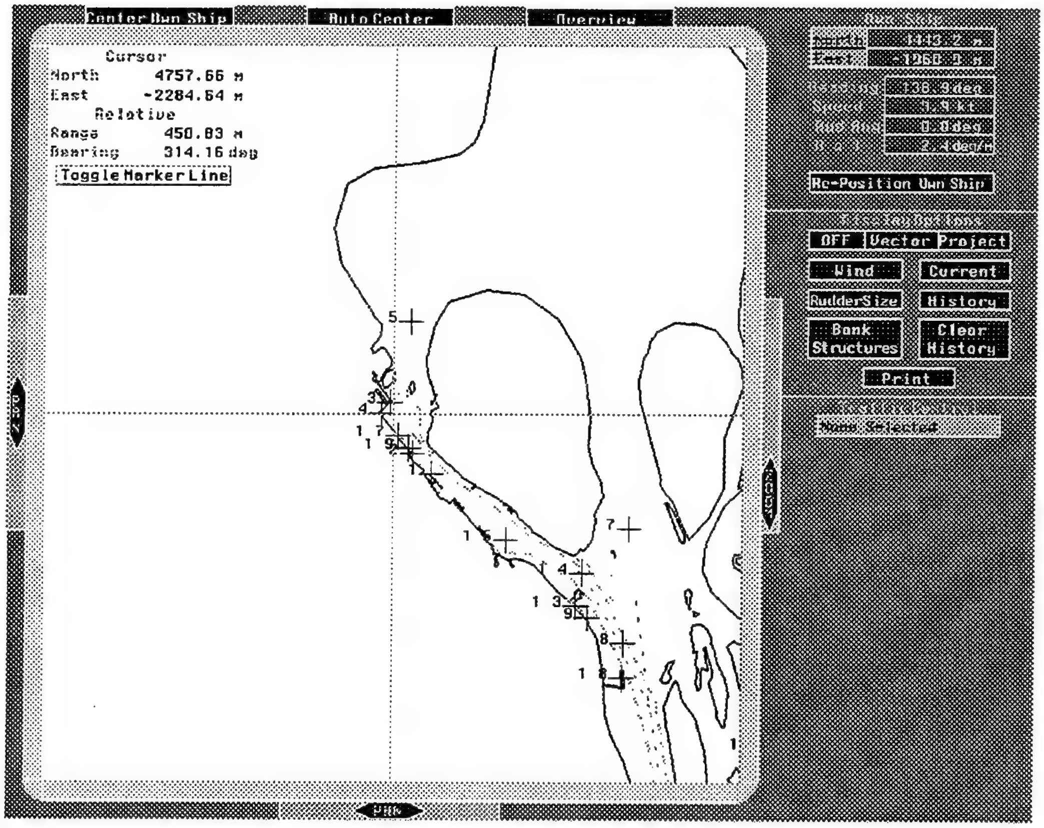

Figure 4:
VESUB Visual Situation Display (VSD) Screen

instructor has access to all traffic ships and can monitor any preprogrammed traffic ships or take manual control of any ship during the training exercise. The left side of the VSD screen is a top-down view of the harbor. This view shows the location of the trainee's submarine (ownship) and all of the traffic ships used in a given training scenario. It also displays geographic features of the database, such as the channel boundaries, navigation aids, buoys, piers, etc. This top-down view can be adjusted to various ranges and the instructor can use the slide bars located on the sides of the display to pan to any location in the database or to zoom in or out to display the necessary

level of detail. Although not shown in Figure 4, the controls which allow the instructor to access and control the traffic ships are located in the lower right quadrant of the VSD. Also located in this quadrant is an icon-based interface which displays specific traffic status information (e.g., angle on the bow, closest point of approach, range, etc.). In the upper right quadrant are similar controls to change the position and heading of ownship and displays with information on ownship status.

The instructor also interacts with a series of windows located on the monitor of the main system computer (Onyx). One of these windows is used to turn the system on at the beginning of an exercise (see Figure 5). Then, during the exercise, this window disappears and the monitor displays what the trainee views in the virtual world through the HMD and allows the instructor to observe the critical objects that the trainee is watching. After a scenario has been completed, the screen in Figure 5 is used to replay the exercise to provide performance feedback to the trainee.

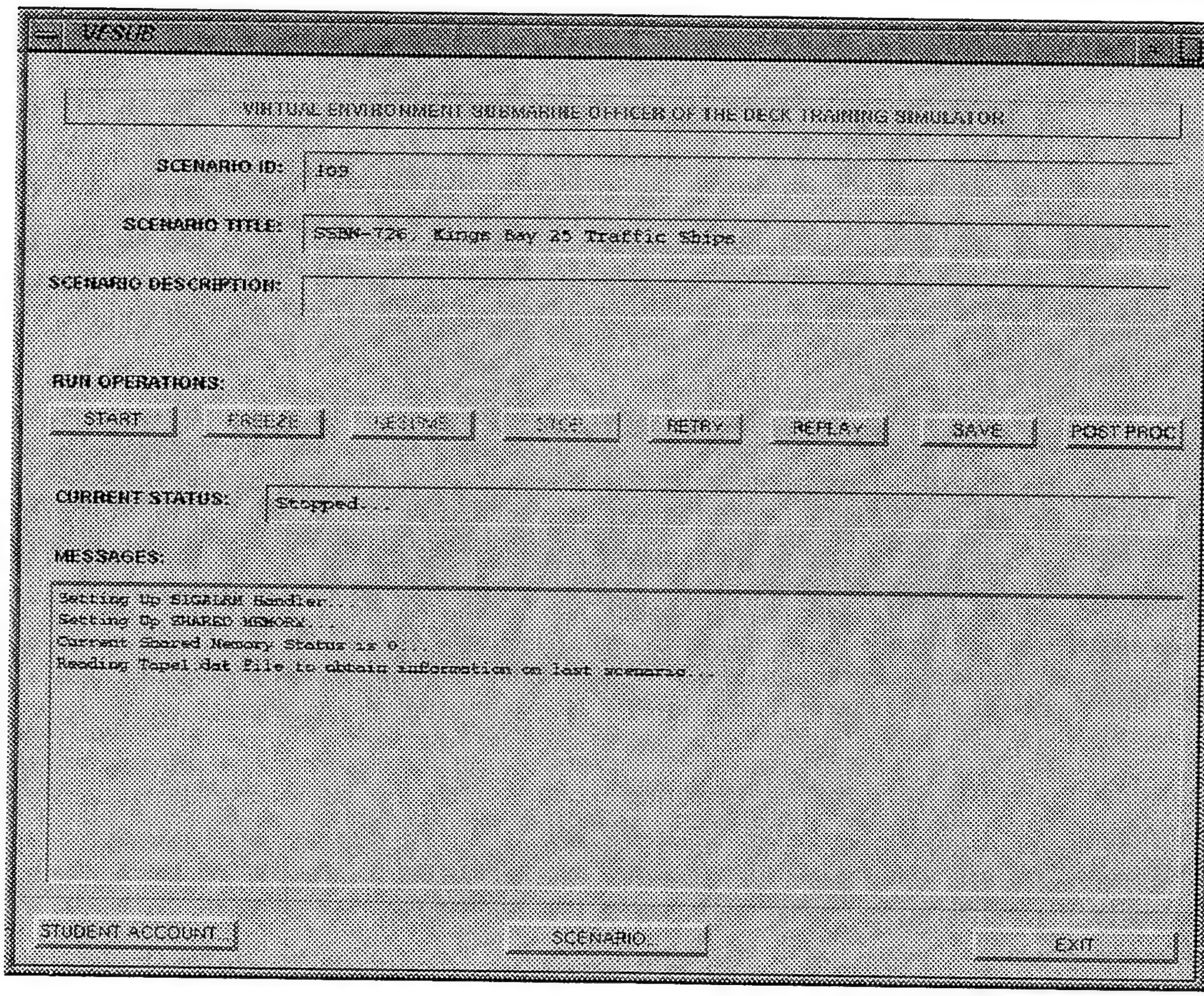

Figure 5: VESUB Start-Up Screen

USABILITY DESIGN HEURISTICS

A variety of guidelines have been developed to assist computer system designers to focus on the needs of the user (e.g., Card, Moran, & Newell, 1983; Williges & Williges, 1984; Hamel & Clark, 1986; Smith & Mosier, 1986; Marshall, Nelson, & Gardiner, 1987; Helander, 1988; Shneiderman, 1992). Similar to many of these, Molich and Nielsen's (1990) ten usability design heuristics were used to analyze the VESUB Instructor Station. The heuristics are as follows:

> [1] • *Simple and natural dialogue*. Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. All information should appear in a natural and logical order.
> [2] • *Speak the users' language*. The dialogue should be expressed clearly in words, phrases, and concepts familiar to the user, rather than in system-oriented terms.
> [3] • *Minimize the users' memory load*: The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
> [4] • *Consistency*: Users should not have to wonder whether different words, situations, or actions mean the same thing.
> [5] • *Feedback*: The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
> [6] • *Clearly marked exits*: Users often choose system functions by mistake and will need a clearly marked 'emergency exit' to leave the unwanted state without having to go through an extended dialogue.
> [7]• *Shortcuts*: Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users.
> [8] • *Good error messages*: They should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
> [9] • *Prevent errors*: Even better than good error messages is a careful design that prevents a problem from occurring in the first place.
> [10]• *Help and documentation*: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, be focused on the user's task, list concrete steps to be carried out, and not be too large. (Nielsen, 1993, p. 20).

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ANALYSIS METHOD

Fourteen students from the graduate level "Human-Computer Interface Usability Evaluation and Design" class at the University of Central Florida performed the usability analysis of the VESUB IOS. The class was divided into four groups and each group conducted an independent analysis applying Nielsen's (1993) usability design heuristics.

ON-SITE DATA COLLECTION

Data for the analyses were collected during three sessions in the VESUB laboratory at the NAWCTSD. These data collection sessions allowed the student analysts to iteratively probe the design and functionality of the VESUB IOS. During the first analysis session, the VESUB research team provided an initial orientation demonstration of the system, followed by a two-hour question and answer period that focused on each control and display on the IOS. The analysts were able, in an unstructured format, to ask the VESUB research team as many questions as necessary to fully understand each IOS function. Because of the complexity of the VESUB IOS, another, three-hour, question and answer session was required to fully cover all of the IOS features and functionality. A third session with only the analysis group leaders was conducted to provide more detailed information on various IOS functions. During this session, prints of the IOS screens were provided to the team leaders for use in their in-depth, off-site analyses. The VESUB research team explained that many of functions and features of the IOS could not be changed in the technology demonstration system due to schedule and budget constraints. However, the students were told that the results of their analyses would be reanalyzed by the research team and used as recommendations for the development of the specifications for the follow-on VESUB operational system.

OFF-SITE ANALYSIS

The analysis teams took the data collected in the three VESUB laboratory sessions and collectively assessed the VESUB IOS design against Nielsen's (1993) design heuristics. The first step in this analysis was to develop VESUB Instructor Task Flow models. These task flow models and the VESUB IOS screen prints were then used to guide the more detailed usability analyses.

Each VESUB IOS control, display, and instructor task was evaluated against the ten design heuristics and those which violated any of the heuristics were classified as either high, medium, or low. Design violations classified as high were assessed as severely hampering system usability and, therefore, should be resolved prior to fielding the operational VESUB system. Medium level violations were those determined to require redesign, but were judged less critical than the high level violations. Design problems classified at the low level, violated one or more heuristics, but were judged as not to impede the practical use of the system. The students, compiled their analyses into four reports which were turned in for class credit. The reports were then provided to the VESUB research team to use as deemed appropriate.

POST-HOC ANALYSIS

During the question and answer sessions, the VESUB research team explained to the analysts that the VESUB system was still under development and that many of the IOS usability problems were already recognized by the research team and would be improved in later iterations of the software. Nevertheless, the students conducted their analyses on the IOS as it was configured at the time. It was further explained, that due to budget and schedule constraints, some of the IOS design violations would have to remain in the demonstration system, but would be corrected during the development of the operational VESUB system.

Upon receipt of the analysis reports, each member of the VESUB research team conducted an independent review and evaluation of the identified IOS design violations. Based on their experience with the development and use of VESUB and other training system instructor stations, the team members selected those violations that, in their opinion, were most detrimental to system usability and were required to be improved in the operational VESUB system. After their separate reviews, the research team met for focused discussions to prioritize the IOS design violations and select those to be highlighted in this report.

RESULTS

The analysis teams produced four separate analysis reports for class credit and also provided copies of the reports to the VESUB research team. Geary, Cahill, and Bowen (1997) identified 39 usability design violations, 22 of which were designated as high priority. Biehl, Pharmer, Rhodenizer, and Wohlschlaeger (1997) found 21 design deficiencies, with 16 designated as high priority. Lanham, Rami, Reeves, and Torizzo (1997) denoted 13 high priority items from the 29 design violations they identified. Elaarag, Tyler, and Vincenzi (1997) suggested serious redesign consideration should be given to 18 high priority items from the 32 design violations identified in their analysis.

During their review and discussions of the IOS design violations reported by the graduate students, the VESUB research team prioritized the violations, eliminating those that were either minor, already corrected, or that were based on the student's incomplete understanding of either the system or the training task. In several cases, due to differences in interpretation and emphasis, the analysts identified the same violation under different heuristics. The VESUB research team regrouped these violations under the most relevant heuristic. The results of this post hoc analysis by the VESUB research team are shown in Table 2. In some cases, the same or similar violations were identified by multiple groups, but with slightly different emphasis. To ensure complete coverage, these similar observations are shown in Table 2.

Table 2

VESUB IOS Usability Design Violations

Analysis Team	Usability Heuristic	
	1. Simple & Natural Dialogue	**2. Speak the User's Language**
Lanham, et al.	• Information not presented in a logical order • Displays irrelevant or extraneous information	• Not all the information is expressed in words that convey the appropriate message
Elaarag, et al.	• "Information Clutter" (same info. found in several places) • Interlinked info. on each screen	• Confusing abbreviations
Geary, et al.	• Extraneous controls	
Biehl, et al.	• Redundant information	• Confusing labels

Table 2: Continued

Analysis Team	Usability Heuristic	
	3. Minimize the User's Memory Load	**4. Consistency**
Lanham, et al.	• Difficult to start the system using multiple keyboards	• Inconsistencies in color and shape of controls
Elaarag, et al.	• Long start-up procedure with potential for errors • No prompts for right mouse button functions	• Different scales of measurement on each screen • Inconsistent terminology
Geary, et al.	• No instructions for keystroke controls • Placement of controls do not follow percentage of use	• Controls activated in different manners
Biehl, et al.	• Too many displays	• Inconsistent colors when controls are activated • Not consistent with "pull down" menu systems
	5. Feedback	**6. Clearly Marked Exits**
Lanham, et al.	• No effective feedback for user	• No exits to back out from options
Elaarag, et al.	• Limited info. on scenario events during run	• No "Undo"
Geary, et al.	• No feedback during "freeze" mode	
Biehl, et al.	• No feedback on "clear history"	
	7. Shortcuts	**8. Good Error Messages**
Lanham, et al.	• No shortcuts	• No error messages
Elaarag, et al.	• Few shortcuts with little guidance	• No warnings for "clear history"
Geary, et al.		• Autocenter allows own ship too near screen edge
Biehl, et al.	• No shortcut for adjustment of HMD eye position	
	9. Prevent Errors	**10. Help and Documentation**
Lanham, et al.	• Few preventative measures against errors in SIMGEN	• No documentation (at time of analysis)
Elaarag, et al.		• No on-line help
Geary, et al.	• No indication that right or middle mouse button functions are active	
Biehl, et al.	• No "Undo" to reverse mistakes	• No on-line help

DISCUSSION OF IOS DESIGN VIOLATIONS

Because AME developed VESUB using the IOS screens already implemented on their Virtual Ship product, and because of budget and schedule constraints, many of the usability design violations could not be corrected in the technology demonstration system. Nevertheless, the violations discussed below should be recognized and every effort should be made to reduce or eliminate as many of the usability design violations as possible in the specification for the operational VESUB system.

SIMPLE AND NATURAL DIALOGUE

> Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. All information should appear in a natural and logical order (Nielsen, 1993, p. 20).

Three major IOS usability design violations were identified under this heuristic: 1) illogical organization of information, 2) irrelevant or extraneous information, and 3) interlinked information on multiple screens. Lanham, et al. (1997) pointed out that the information on the IOS screens was not ordered in a "natural or logical order where the user would initially gaze" (p. 5). Persons in English speaking cultures are used to reading from left to right and top to bottom. They unconsciously search for the most important information in the upper left corner of the screen. The controls that the instructor uses most often (e.g., *Freeze, Unfreeze,* and *Stop*), are placed in the center of the screen. A simple fix for this problem would be to move this control box to the upper left.

Three out of the four analysis groups (Lanham, et al., 1997; Geary, et al., 1997; and Biehl, et al., 1997) stated that the IOS presented irrelevant or extraneous information. An example of this extraneous information is found in the displays at the top of the SCD screen shown in Figure 3. This series of displays shows various system states. These same states are also found on system control buttons or on displays in other areas of the SCD screen or on the VSD screen. For example, the run mode buttons (F*reeze*, etc.) turn white and change labels (e.g., *Freeze* changes to *Frozen*) when activated. This information is also shown under the system status display at the top of the screen. Numerous examples of such redundant information were identified. It may be possible to reduce the number of screens needed at the IOS if all of the redundant information is eliminated.

Elaarag et al. (1997) pointed out that the SCD and VSD screens display inter-linked information. This can cause confusion and uncertainty in the user, who should only have to look in one area to find a specific piece of information. This is especially true in early versions of the software, which displayed conflicting information (e.g., distances in feet on one screen and meters on another). The IOS screens should display universal standards of measurement for the ship

handling task (e.g., navigation principles require use of latitude, longitude, yards, nautical miles, feet, fathoms, etc.). When selected, these measures should be consistent across all screens.

SPEAK THE USER'S LANGUAGE

"The dialogue should be expressed clearly in words, phrases, and concepts familiar to the user, rather than in system-oriented terms" (Nielsen, 1993, p. 20).

Lanham, et al. (1997) and Elaarag, et al. (1997) found problems with the labeling of several controls. Either the labels were confusing or they used terminology that the analysts felt would not be familiar to Navy users. For example, the *Xmit Cmd* button is required to execute a variety of selected changes. The analysts recommended that a more familiar term, such as "Execute," replace this button. Another example is the two controls on the VSD screen (Figure 4) that are labeled *Vector* and *Project*. These controls are used to display either the future course of the own ship based on its current heading (*Vector*) or the course the own ship is expected to travel over the next three minutes (*Project*). The analysts recommended that these buttons be relabeled using Navy terminology (e.g., "Current Course" and "Proj Course").

MINIMIZE THE USER'S MEMORY LOAD

"The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate" (Nielsen, 1993, p. 20).

Three of the analysis teams (Lanham, et al., 1977; Elaarag, et al., 1997; and Biehl, et al. 1997) determined that the start-up procedure was too long and complex because it required the user to interact with all three monitors, keyboards, and mice. These complex interactions are due, in part, to the demonstration nature of the system. However, the VESUB research team strongly concurs with this analysis and will recommend that the operational VESUB systems require interaction with only one keyboard and mouse for system start-up.

Elaarag, et al. (1997) and Geary, et al. (1997) both identified a deficiency in prompts for certain controls. In some cases, the right or middle mouse buttons are used to bring up displays, but there are no prompts for these actions. Keystroke commands on one of the keyboards are required to initiate some actions (e.g., turning off fog in the visual scene). There are no prompts for these keystroke commands. In all cases, the system user should be provided with an easy to understand prompt as guidance for systems functions. These prompts could be automatically displayed when the instructor places the cursor on an icon or the instructor could point and click on a help icon.

CONSISTENCY

"Users should not have to wonder whether different words, situations, or actions mean the same thing" (Nielsen, 1993, p. 20).

It is essential for system usability that its interface screens be designed to be as consistent as possible. The analysts found several inconsistencies that will detract from system effectiveness. Lanham, et al. (1997) and Biehl, et al. (1997) found that some controls were inconsistent in their color, shape, and color changes when activated. Some controls change from blue to white when activated, others change from light blue to dark blue, others change from yellow to green, and still others change from green to red. These inconsistencies probably stem from the growth and change of the Virtual Ship system during several years of development by various system designers and programmers at AME. Nevertheless, all controls should be modified to display the same color when activated. Furthermore, the controls should be modified to have the same shape whenever possible.

More problematical than the color inconsistencies, Elaarag, et al. (1997) identified different measurement scales on each screen. This is another artifact of the development of the Virtual Ship system by a variety of different programmers. Nevertheless, improving the consistency across screens has been a major goal of the VESUB research team. The final version of the VESUB technology demonstration system will display all measurements using standard Navy terminology. This will also be true for the operational VESUB systems.

A third source of inconsistencies was identified by Geary, et al. (1997). They found that various controls were activated in different manners. In most cases, controls are on/off toggles. However, in a few cases, an "off" button must be accessed to turn off a feature. The specification for the operational systems will include a requirement for all controls to be consistently activated and deactivated.

Each group of analysts indicated that usability would be enhanced if all controls and displays were consistent with "pull down" menu systems. Since many users are familiar with standard "windows" applications, this is a cogent recommendation.

FEEDBACK

"The system should always keep users informed about what is going on, through appropriate feedback within reasonable time" (Nielsen, 1993, p. 20).

All analysts identified a dearth of feedback for the user. This is especially evident during "freeze" mode. While the system is "frozen," the instructor can change various system states, such as visibility or time of day. However, no actual changes occur until the system is placed in "run" mode. Furthermore, no indications are provided to remind the instructor which changes have been made. Either the instructor must remember a potentially large list of changes, or make

them one or few at a time by constantly switching between "freeze" and "run." Neither option is recommended. The operational VESUB systems should provide immediate feedback on any system status changes made by the instructor, regardless of system mode.

Elaarag, et al. (1997) also pointed out that except for time, no feedback on events in the scenario is provided to the instructor during a run. It would be helpful for student evaluations if the instructor had a method to track student progress and to determine which of the preprogrammed instructional events have occurred (e.g., closest point of approach (CPA) of each traffic ship, degree of set and drift of ownship due to currents, bearing of each traffic ship to ownship).

A potential problem with the "clear history" function was identified by Biehl, et al. (1997). When the instructor selects *Clear History*, all the historical tracks of own ship and traffic ships are permanently erased. Some form or warning or recovery mechanism should be available for this and all other instructor actions.

CLEARLY MARKED EXITS

"Users often choose system functions by mistake and will need a clearly marked 'emergency exit' to leave the unwanted state without having to go through an extended dialogue" (Nielsen, 1993, p. 20).

This heuristic relates to the item discussed above. People, even instructors, make mistakes. The current configuration of the Instructor Station provides no way to back out from an unwanted state (Lanham, et al., 1997; Elaarag, et al., 1997). The "undo" function and other methods to correct mistakes should be included in the specification for the Instructor Station of the operational VESUB systems.

SHORTCUTS

"Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users" (Nielsen, 1993, p. 20).

Once a system user becomes an expert, he or she may want methods to accelerate various operations. Lanham, et al. (1997) identified no operator shortcuts in their analysis. Biehl, et al. (1997) suggested that a high priority shortcut should be added for adjustment of the eye position in the HMD. Currently, the instructor must use the keyboard to adjust the eye position for each trainee. A setup file with the height of the trainee and other pertinent information (e.g., the last scenario the trainee successfully completed) could be provided. With such a file, the system would automatically set the eye position each time a given trainee logged in and entered the system.

Elaarag, et al. (1997) identified a few keystroke shortcut commands that are currently available in the system. However, there are no instructions or indicators for these keystroke commands. As with all system functions, clear instructions and indications of system states should be easily accessed by the instructor.

GOOD ERROR MESSAGES

"They should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution" (Nielsen, 1993, p. 20).

Just as the system should provide exits to retreat from errors, it should also provide warnings that help the user avoid errors or identify the type and location of an error already made. Warnings are often designed as a brightly colored or blinking window that asks the user if he or she really wants to perform the selected action. This gives the user a chance to reconsider the action and the possibility to change his or her mind.

Lanham, et al. (1997) could find no error messages available in the system. Elaarag, et al. (1997) pointed out that the lack of warnings for the "clear history" function is an especially acute problem. As discussed above, once the *Clear History* button is activated, there is no way for the instructor to recover. There should be a clear warning for the instructor after the *Clear History* button has been selected. This warning should require at least one additional keystroke before the system erases the history information.

Geary, et al. (1997) identified a problem with the "autocenter" function. When the *Autocenter* button is activated, this function automatically centers the own ship icon on the VSD screen. As currently implemented, the own ship must move to approximately one half inch from the edge of the screen before the system recenters the icon. These analysts felt that autocenter should be activated earlier so the instructor can view more of the channel in front of the own ship. Perhaps the "autocenter" distance should be selectable by the instructor since different harbors or channels within a harbor may present unique problems that require different default distances for "autocenter."

PREVENT ERRORS

"Even better than good error messages is a careful design that prevents a problem from occurring in the first place" (Nielsen, 1993, p. 20).

Lanham, et al. (1997) pointed out that there are few preventative measures against errors in the scenario generation software, called Simulation Generation (SIMGEN). Many initial conditions must be established for each scenario prior to accessing the graphic editor screen to position and program traffic ships. If any errors are made during the definition of initial conditions, the system will not allow the instructor to move to the graphic editor. Unfortunately, there are no mechanisms to prevent the user from entering erroneous or conflicting set-up data.

Furthermore, when an error has been made, the user does not know it until he or she tries to access the graphic editor. At this point, the only way to find the error is to go through the text of the initial conditions file, line by line. This is extremely time consuming and frustrating for the user. The operational VESUB systems should provide internal error checking mechanisms that will help prevent data entry errors during scenario construction. If an error is made, the system should highlight the error so the user can easily correct it.

Geary, et al. (1997) pointed out that the user interface provided no indications when the right or middle mouse button functions were activated. Without such indications, the instructor can forget that a function is active or forget how to deactivate it. Unwanted active functions promote screen clutter, which can precipitate additional errors.

Biehl, et al. (1997) observed that the inclusion of an "undo" function would help prevent errors by affording the opportunity for the user to reverse mistakes before they propagate and cause additional errors. As in previous discussions, the VESUB research team strongly urges that the Instructor Station of the operational VESUB systems include an "undo" function.

HELP AND DOCUMENTATION

> Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, be focused on the user's task, list concrete steps to be carried out, and not be too large (Nielsen, 1993, p. 20)

At the time of the usability analyses, the user's manual for the VESUB system had not been completed. The VESUB research team had access to AME's Virtual Ship User's Manual, but this document did not include all of the functionality that had been added to the VESUB technology demonstration system. Lanham, et al. (1997) correctly pointed out that the absence of system documentation was a critical omission. Subsequent to the completion of the usability analyses, several iterations of the VESUB Software User's Manual were produced. The VESUB research team used inputs from Naval Submarine School instructors and instructors from other submarine training facilities to help ensure that the user's manual address all of their needs. All shortfalls in the technology demonstration user's manual were documented and used in the development of the documentation requirements for the operational VESUB systems.

Elaarag, et al. (1997) and Biehl, et al. (1997) observed that the VESUB technology demonstration system provided no on-line help. On-line help can be a very efficient mechanism to answer the user's questions about a specific system function. Some user's prefer on-line help to consulting a user's manual. This is especially true for those users who are familiar with word processing and spread sheet software that includes this function. It is often easier to keyword search through an on-line help database than to consult the index or table of contents of a hard copy user's manual. In some on-line help systems, the user only needs to place the cursor on the area where he or she needs help and the system will automatically find and display the information

needed. Of course, the more complex the on-line help system, the more developmental resources will be required. The acquisition team for the operational VESUB systems will have to determine the level of complexity required in the on-line help system. Nevertheless, on-line help is a feature that is recommended for the operational VESUB systems, regardless of the level of complexity that budgets and schedules will allow.

SUMMARY AND RECOMMENDATIONS FOR THE OPERATIONAL VESUB SYSTEM

The previous section discussed many user-oriented design violations. One of these has been corrected in the demonstration system, others have only been partially corrected. Still others must be corrected when the operational VESUB system is designed and built. To facilitate this process, Table 3 summarizes the design violations, their current status, and the implications for training if they are not corrected. In general, the IOS should be designed to minimize the effort necessary to operate the system so the instructor can devote his or her time to observing and coaching the trainee. All of the recommendations in Table 3 lead to this goal.

Table 3

Summary and Status of IOS Design Violations

USER-ORIENTED DESIGN VIOLATION	STATUS*	TRAINING IMPLICATION
1. Simple & Natural Dialogue		
• Illogical organization of info	• PC	• Instructor must be able to access information quickly so attention can be directed toward the trainee. The most important information should be located in the upper left portion of the screen, least important in the lower right.
• Irrelevant or extraneous info or controls	• PC	• Only necessary info should be displayed so instructor does not become confused when looking for important information. This is also true of controls. Only one set of controls should be required for each function and the purpose for each control should be easy to understand.
• Interlinked info	• PC	• Instructor should only have to look in one spot for a piece of information
2. Speak the User's Language		
• Some labels use unfamiliar terminology, confusion labels, or abbreviations.	• PC	• All controls and displays should use terminology that is familiar to a Navy instructor so he or she does not have to guess or consult the user's manual to determine a control's functionality.

* Note: C = Corrected in demo system; PC = Partially corrected; OS = Requires Correction in operational system

Table 3: Continued

USER-ORIENTED DESIGN VIOLATION	STATUS*	TRAINING IMPLICATION
3. Minimize User's Memory Load		
• Complex start-up procedure	•OS	• The operational VESUB system should be "turn key," it should not require complex start-up procedures.
• Lack of prompts for controls	• OS	• Instructor should receive a prompt when placing the cursor on a control.
• Placement of controls should follow percentage of use	• OS	• Instructors should be able to most easily find the controls used most often. The most important controls should be located in the upper left of the screen, the least important in the lower right.
4. Consistency		
• Controls do not have same colors for same functions (e.g., on/off)	• OS	• Operational system controls should all be one color for a given state (e.g., green = on, red = off) to minimize confusion.
• Different measurement scales	• PC	• Measurement scales should never differ on different screens. This is especially important when positioning ships during scenario construction so they appear in the correct location during the exercise.
• Different ways to activate controls	• OS	• Instructor should always activate controls in the same manner so he/she does not make a mistake at a critical time in a scenario.
• Controls & displays should follow "pull-down" menu conventions.	• OS	• Most users are familiar with "pull-down" menus, like those found in typical word processing software. This familiarity will make it easier to learn and use the system.
5. Feedback		
• Lack of feedback especially during system "freeze" state	• OS	• Instructor should not have to wait until the system is in "run" mode to see whether commands have been correctly activated.
• Limited real-time feedback on system states (except time) during a scenario run.	• OS	• Instructor should be provided with trainee and system status during an exercise. Information on which critical scenario events have occurred and their status is required.
• No warning on "clear history"	• OS	• Instructor should be "warned" any time he/she tries to take make a nonrecoverable action.
6. Clearly Marked Exits		
• No "undo" functions	• OS	• Instructor should be able to back out of any action. No mistake should be "fatal."

* Note: C = Corrected in demo system; PC = Partially corrected; OS = Requires Correction in operational system

Table 3: Continued

USER-ORIENTED DESIGN VIOLATION	STATUS*	TRAINING IMPLICATION
7. Shortcuts • No instruction for shortcut (keystroke) commands • No shortcut for HMD and other setup procedures	• OS • OS	• Experienced instructor can save time by using shortcuts. These should be documented in the User's Manual. • Instructor should be able to quickly and easily set up the HMD eye position and other configurations of the system for each trainee. A setup file, established the first time a trainee uses the system could reconfigure it each time the trainee returns for additional training.
8. Good Error Messages • No error messages	• OS	• The IOS should provide error messages any time the instructor tries to activate a function that will cause a major change in the system state.
9. Prevent Errors • No error checks in "SIMGEN" • No indication when right and middle mouse buttons are active	• OS • OS	• During the construction of complex scenarios, many individual, possibly conflicting items of information must be entered. The instructor should be prompted when an error has been made and the system should highlight the error so it may be corrected quickly. • The instructor should have an indication when any function is active. Without such indications, it is easy to lose track and make mistakes.
10. Help and Documentation • No User's Manual • No on-line help	• C • OS	• The User's Manual is essential for training of the instructor in the operation of the system. • The instructor's job can be greatly facilitated with the inclusion of on-line help functions. He/she should be able to place the cursor on a control and hit help to get an explanation of the function. This will allow inexperienced instructors to continue their activities without having to stop and look things up in the User's Manual.

* Note: C = Corrected in demo system; PC = Partially corrected; OS = Requires Correction in operational system

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RECOMMENDATIONS FOR FUTURE RESEARCH IN IOS DESIGN

The complexity of the VESUB technology demonstration system and the necessity to build on existing products resulted in numerous usability design violations which will compromise the training effectiveness of the operational VESUB system if they are not corrected. The major focus of the VESUB demonstration development effort has been on the functionality of the software. This was necessary to meet the requirements to train the ship handling task. Due to schedule and budget constraints, less effort has been devoted to the user-oriented design of the IOS. Many of the design violations discussed in the previous section could have been avoided if the focus during system development had been directed more towards the needs of the instructor. It is recommended that future computer-based and VR training system developers commit themselves and their resources to improved system usability from the inception of system development. This level of commitment will help ensure consistency and usability in all components of their instructor stations.

In addition to the VESUB IOS design improvements discussed in the previous section, the following are recommended areas for specific instructor-oriented research and technology development which will increase the usability of future training systems. This list is not comprehensive, but includes those developments that the VESUB research team, based on the lessons learned during system development and their experience with other training systems, believes to have the highest payoff for improvements in the user-oriented design of training system instructor stations.

STANDARDIZATION OF IOS GRAPHICAL USER INTERFACES (GUIs)

Most instructors today are familiar with basic computer functionality, such as word processing and other office productivity software. These software packages have, for the most part, standardized their interfaces on the "windows" GUI configuration. Future training systems should follow this lead and standardize their IOS using "windows" style GUIs. These interfaces should be built around "pull down" menus with easy to understand labels. These interfaces should follow the usability design recommendations discussed above (e.g., be consistent, use language the instructor understands, include emergency exits).

ON-LINE HELP

Another software feature of many office application software is the provision of an on-line help function. On-line help allows the user to ask questions and receive answers as he or she interacts with the system. This is more efficient than having to stop and consult written documentation like a user's manual. On-line help does not eliminate the need for user's manuals. Rather it can supplement written documentation and make it easier for the instructor to remain focused on the primary task, providing instruction to the trainee.

EMBEDDED INSTRUCTOR TRAINING

In recent years, greater emphasis has been placed on the development of embedded training. Embedded training refers to training that is included in or added on to operational equipment. The theory is that embedded training is highly effective because it is delivered in the same environment and context where operational tasks are performed. Thus, transfer from training to operational performance should be improved by effective embedded training.

The operational tasks required of instructors is running a training system and providing training. Any computer-based or VR training system should include embedded instructor training tools that provides information on the complete, correct, and efficient operation of all training system functions. The effectiveness of any training system is highly dependent on the capability of the instructor. Embedded instructor training should greatly improve the instructor's ability to optimize the effectiveness of the training equipment.

TASK ANALYSES FOR INSTRUCTOR TASKS

Task analyses have traditionally been directed toward an understanding of the operational task for which training is being developed. Emphasis should also be directed toward a better understanding of the instructor's tasks. The results of the instructor tasks analysis could be provided to system developers early in the design of the training system so the necessary resources and technologies can be brought to bear on the requirements of the instructor and the design of the instructor station.

VOICE RECOGNITION AT THE IOS

The VESUB system has successfully demonstrated that speaker-independent voice recognition and speech synthesis can be used to enhance the experience of the trainee. These technologies also have the potential to provide missing team member simulation to increase the flexibility and effectiveness of team training. Future training systems can incorporate voice recognition at the instructor station to supplement or replace many point and click actions. For example, if the instructor observes a problem during a scenario, he or she could speak the word "freeze" to instantly pause the scenario. This would allow the instructor to move away from the IOS to more closely observe the trainee and would avoid the loss of time that would occur if the instructor had to grab the mouse, locate and move the cursor to the "freeze" icon, and click to pause the scenario. Research is necessary to determine which instruction activities are amenable to voice recognition and whether inclusion of this capability will improve the performance of the instructor and the effectiveness of the whole training system.

CONCLUSIONS

The VESUB technology demonstration system has successfully integrated VR hardware, software, and courseware to provide a training capability for the submarine OOD, where none previously existed. Developmental constraints, such as budget limitations, schedule deadlines, and technology shortfalls, have bounded the functionality of VESUB. Nevertheless, fleet and school experts are confident that VESUB, based on their interactions with the system during formative evaluations, will be a viable training medium for the ship handling task. It is expected that the results of the training effectiveness evaluations, which will be documented in a separate report, will validate these expert opinions.

Upon the completion of the VESUB research project, the next step is to provide the Navy with an effective and usable operational VESUB system. The operational VESUB system, and other future VR training systems must achieve a balance between task requirements, the latest hardware and software capabilities, proven instructional techniques, and user-oriented IOS interface design. This report has provided information to help build better instructor stations by presenting the results of usability analyses of the VESUB technology demonstration. Similar design violations are likely to occur in any complex simulation-based training system. They can be avoided, only if the needs of the instructor are factored into the requirements for system development.

The IOS design violations identified in this report and the recommendations for their correction will be used to improve the specification for the IOS of the operational VESUB system. They may also be used to help improve the design of the IOS in other future training systems. Increasing the usability of the IOS to allow the instructor to more easily create, monitor, and control training scenarios will significantly contribute to the training effectiveness of VESUB and many other training systems.

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COORDINATION

The VESUB technology demonstration system evolved from a feasibility demonstration system, developed under the Virtual Environment Training Technology project at NAWCTSD. This feasibility demonstration was used during the first year of the VESUB project to solicit inputs from fleet subject matter experts (SMEs) on the required functionality for the VESUB technology demonstration system. During development and formative evaluations of VESUB, numerous fleet SMEs provided guidance to ensure that the system was realistic and provided the necessary functionality to support training for the ship handling task.

The development of VESUB has been immeasurably aided by the support and guidance of the VESUB Implementation Planning Group (IPG). The IPG included members from:

- NAVSUBSCOL (N52), Groton, CT
- SUBTRAFAC (Code 10), Norfolk, VA
- TRITRAFAC, Kings Bay, GA
- SUBGRP 10, Kings Bay, GA
- TRITRAFAC, Bangor, WA
- SUBPAC, Pearl Harbor, HI
- SUBLANT (N742), Norfolk, VA
- CNET (T2223), Pensacola, FL
- CNO (N879C), Washington, DC
- SUBTRAFAC, San Diego, CA

VESUB has been demonstrated to hundreds of visitors to the NAWCTSD laboratories. The success of the integration of hardware and software in VESUB has led to the use of several components in other training systems.

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GLOSSARY OF TERMS, ACRONYMS, AND ABBREVIATIONS

AHD	Ahead
AME	Advanced Marine Enterprises (Now Nichols/Advanced Marine), VESUB System Developers
AOB	Angle on the Bow
AST	Astern
CO	Commanding Officer
COTS	Commercial Off the Shelf
CPA	Closest Point of Approach
GUI	Graphical User Interface
HCI	Human-Computer Interface
HMD	Head-mounted Display
IALA	International Association of Lighthouse Authorities
IOS	Instructor/Operator Station
JO	Junior Officer
LADBM	Large Area Database Management System
NAVAID	Navigation Aid
NAWCTSD	Naval Air Warfare Center Training Systems Division
NTDS	Naval Tactical Data System
OOD	Officer of the Deck
SIMGEN	Simulation Generation Software on VESUB and Virtual Ship
SME	Subject Matter Experts
SPAN	Submarine Piloting and Navigation Training System
VE	Virtual Environment
VESUB	Virtual Environment for Submarine OOD Ship Handling and Piloting Training System
VETT	Virtual Environment Training Technology (6.2 Research Program at NAWCTSD)
Virtual Ship	AME's Commercial Surface Ship Handling Training Product (baseline for VESUB)
VR	Virtual Reality (Synonymous with VE)
VSD	Visual Situation Display
XO	Executive Officer

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APPENDIX A

VESUB Hardware and Software

HARDWARE

Main Computer System: Silicon Graphics Onyx Deskside
- Four R10,000 CPUs
- 256 Mbytes RAM
- One Infinite Reality Graphics Pipe with Two Raster Manager Boards (16 MB Texture Memory)
- Scene Refresh Rate at 30 Hz
- Capable of Displaying Approximately 21,000 Polygons (fully Z-buffered and anti-aliased)

Instructor/Operator Station (IOS):
- Two Silicon Graphics INDY Desktop Computers

Head Mounted Display (HMD): n-Vision Datavisor HiRes
- Resolution: 1280 x 1024 pixels
- Field of View: 40 degrees horizontal and 30 degrees vertical (capable of stereo-optics for up to 70 degrees horizontal view)

Head Tracker: Polhemus 3 space Fastrack (Magnetic)

Printer: Color Postscript, Manufacturer To Be Determined

Sound System:
- Two Radio Shack SSM60 Stereo Sound Mixers
- Two Rane MS1 Microphone Amplifiers
- Two Radio Shack Dynamic CB Microphones, P/N 21-1172
- Two Radio Shack Speakers, Cat. No.: 40-1324

SOFTWARE

Visual Scene:
- Models and Terrain Created Using ModelGen2 from Multigen, Inc.
- Real-time, Interactive 3-D Scene Generation Controlled by SGI's IRIS Performer
- Marine Visual Effects Created Using Vega Marine from Paradigm Simulation, Inc.

Instructor/Operator Station (IOS) Interface:
- IOS Screens Created Using Visual Applications Builder (VAPS) from Virtual Prototypes, Inc.
- Windows in SIMGEN and Start-up Screens Created with X-Designer Release 4.5 from Imperial Software Technology Limited and Data Views Corporation

Audio Effects:
- Audioworks from Paradigm Simulation, Inc.

APPENDIX B

VESUB Training Objectives

PERCEPTUAL COMPONENTS	TRAINING OBJECTIVES
1P. Locating and Identifying Navigation Aids	• The trainee shall be able to locate navigation aids when referenced by the navigator. • The trainee shall be able to recognize navigation aids in the visual field.
2P. Judging Distance	• The trainee shall be able to accurately judge distances to: navaids, contacts, and landmarks. • The trainee shall be able to judge distances relative to track. • The trainee shall be able to verify known distances. • The trainee shall be able to maintain the ship within the acceptable limits of the channel.
3P. Identifying Start and Completion of Turns	• The trainee shall be able to determine relative and true directions on a compass. • The trainee shall be able to determine relative bearings to the navigational aid to be used for turn bearings. • The trainee shall check turn bearings when turning. • The trainee shall be able to recognize when the ship is clear to turn (e.g., when buoys are in line).
4P. Locating, Identifying, and Avoiding Obstacles	• The trainee shall look far enough ahead to evaluate contacts early. • The trainee shall be able to recognize new contacts prior to being informed of the contact. • The trainee shall be able to recognize relative directions and motions. • The trainee shall be able to locate, identify, classify and differentiate between various types of contacts and other obstacles. • The trainee shall take early and effective actions to avoid obstacles or lessen their negative outcomes.
5P. Sense of Ship's Responsiveness	• The trainee shall understand the ship's capabilities and limitations, including: advance and transfer, speed at various engine orders, loss of stearage speed, distance to stop or reverse course.
6P. Recognizing Environmental Conditions	• The trainee shall be able to accurately estimate: sea state, cloud cover, direction and velocity of current, wind direction and speed, and time of day. • The trainee shall be able to accurately judge the state of visibility.
7P. Recognizing Equipment Failures	• The trainee shall stay alert for equipment failures. • The trainee shall regularly monitor rudders, indicators, and other equipment.
8P. Detecting & Filtering Communications	• The trainee shall be able to recognize communication sources and proper/improper repeat backs.

APPENDIX B: Continued

COGNITIVE COMPONENTS	TRAINING OBJECTIVES
1C. Understanding the Relationship of Visual Cues to Chart(s)	• The trainee shall be familiar with all the navigation aids to be used. • The trainee shall understand how to read ranges (fore and aft). • The trainee shall understand how to determine if the ship is left/right of track versus left/right of range. • The trainee shall understand when to attempt to drive the ship in the center of the channel. • The trainee shall understand buoyage systems (e.g., IALA "A" and "B" systems). • The trainee shall understand the inaccuracy of buoys. • The trainee shall understand the accuracy/inaccuracy of Fix information.
2C. Understanding Relative Size and Height/ Range Relationships, and Angle on the Bow	• The trainee shall understand how to determine contact mast head height. • The trainee shall know his height of eye. • The trainee shall know how to determine: size and distance relationships to navaids, contact length, distance to the horizon, hull down, and angle on the bow.
3C. Understanding Advance and Transfer	• The trainee shall understand the concepts of advance and transfer. • The trainee shall understand ship characteristics like tactical diameter of own ship. • The trainee shall understand the criticality of turning the vessel the wrong way. • The trainee shall understand the principles of conning the ship through turns. • The trainee shall understand when to turn the ship based on the use of a slide bar. • The trainee shall understand the principles of compensation. • The trainee shall compensate for set and drift when making turns. • The trainee shall check that the next channel is clear prior to turning. • The trainee shall not drive based solely on the Navigator's recommendations.
4C. Understanding the Effects of Tides, Currents, Wind, and Seas	• The trainee shall understand how the wind affects the height of seas. • The trainee shall understand that current and tides tend in the direction of the natural geography. • The trainee shall understand the relationship of the estimated winds associated with various sea heights. • The trainee shall understand that sea height influenced by wind speed can give false indications of the actual direction of currents.
5C. Understanding Rules of the Road	• The trainee shall comprehend the criticality of Rules of the Road. • The trainee shall correctly exercise Rules of the Road by taking appropriate actions in: overtaking, meeting, passing, and crossing situations. • The trainee shall understand the rules for sound signals and responses. • The trainee shall take appropriate action when nearing a bend in the channel. • The trainee shall take appropriate actions to avoid collisions.
6C. Understanding Relative Motion (Direction & Speed)	• The trainee shall understand true and relative bearing and their significance. • The trainee shall be able to convert relative to true and true to relative. • The trainee shall be able to determine the relative direction of contacts. • The trainee shall be able to determine own ship's motion relative to fixed objects.

APPENDIX B: Continued

COGNITIVE COMPONENTS	TRAINING OBJECTIVES
7C. Understanding Methods to Differentiate and Prioritize Traffic Contacts	• The trainee shall be able to classify, differentiate, and prioritize various types of contacts and other obstacles. • The trainee shall understand safe distances to hazards. • The trainee shall be able to effectively determine contacts of interest. • The trainee shall correctly assign master control numbers to contacts of concern. • The trainee shall maintain awareness of contacts in relation to own ship. • The trainee shall prompt personnel for supporting information. • The trainee shall drop contacts of interest when no longer of concern. • The trainee shall be able to correctly determine contact's angle on the bow.
8C. Understanding Ship's Operation Under Harbor Directives	• The trainee shall understand harbor, port limitations, restrictions, & regulations.
9C. Understanding Methods to Deal with Uncooperative Traffic	• The trainee shall take proper and effective actions to avoid encounters with uncooperative traffic.
10C. Understanding Correct Operation of Ship's Systems	• The trainee shall understand the correct operation of bridge equipment. • The trainee shall verify rudder orders by: visually checking the rudder and the bridge suitcase indicator. • Does the trainee verify engine orders by: checking the bridge suitcase indicator and observing screw wash?
11C. Understanding When and How to Take Corrective Actions	• The trainee shall understand emergency operating procedures.
12C. Understanding Effective Communication Procedures	• The trainee shall speak clearly. • The trainee shall use correct terminology. • The trainee shall effectively communicate with each station using required terminology. • The trainee shall acknowledge all reports and repeat backs. • The trainee shall inform appropriate personnel about his actions. • The trainee shall not clutter the circuits.

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